U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Station Blackout: A case study in the interaction of mechanistic and probabilistic safety analysis

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RISMC strategic goals

- **Goals of the RISMC Pathway:**
  1. Develop and demonstrate a risk-assessment **method** coupled to safety margin quantification that can be used by nuclear plant decision makers as part of their **margin management strategies**
  2. Create advanced "**RISMC toolkit**" that enables more accurate representation of nuclear **plant safety margin**

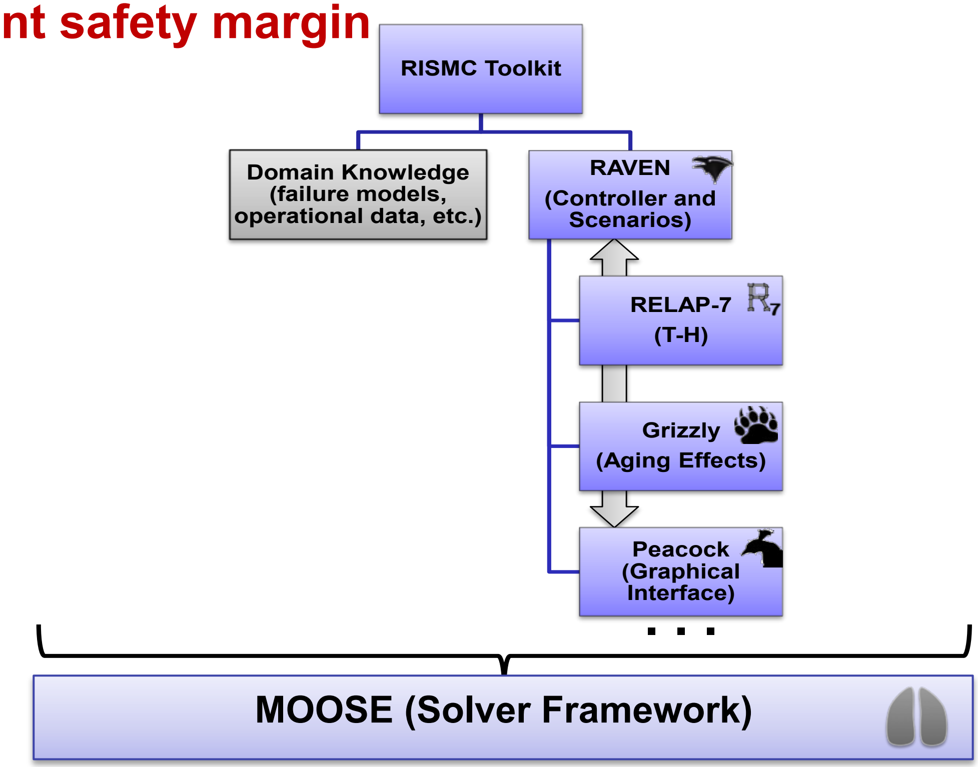
RISMC methods understood

↓

Now applying RISMC methods to make it useful for decision makers

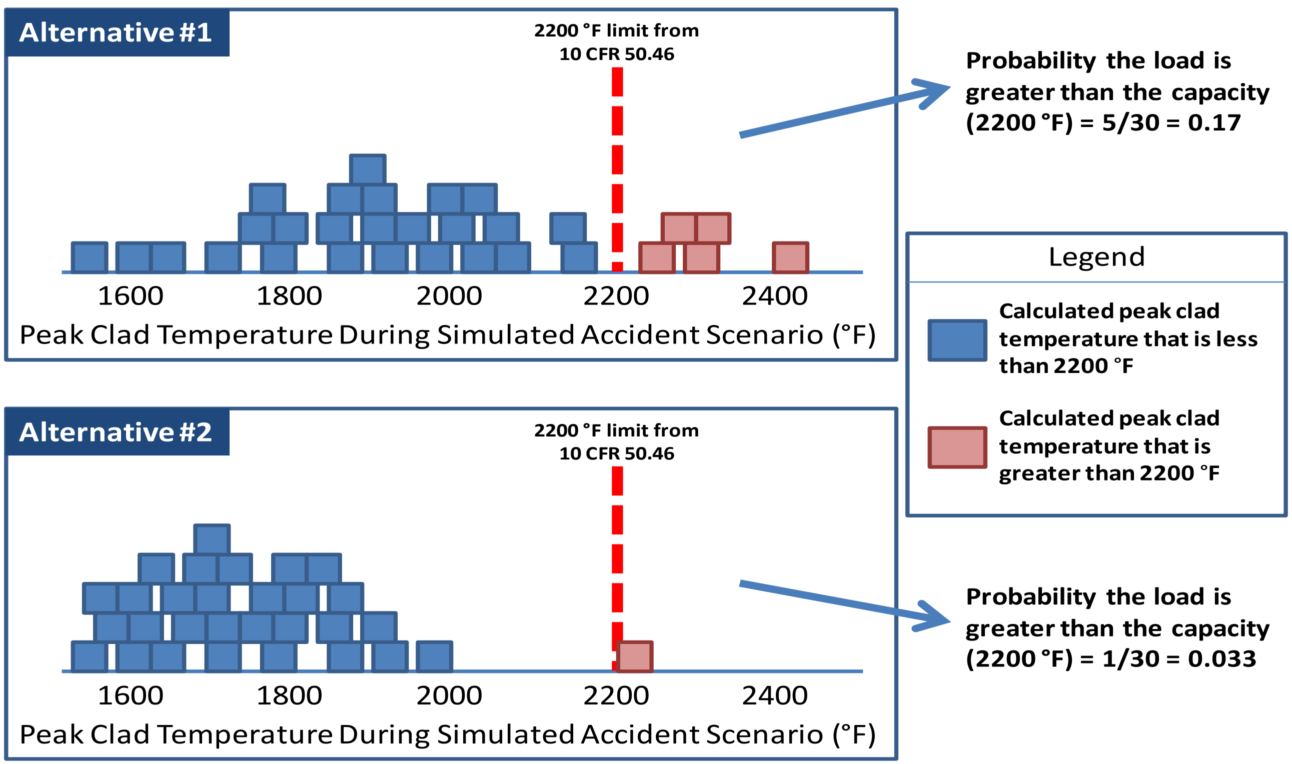
↓

Currently refining some of the technical aspects of the methods



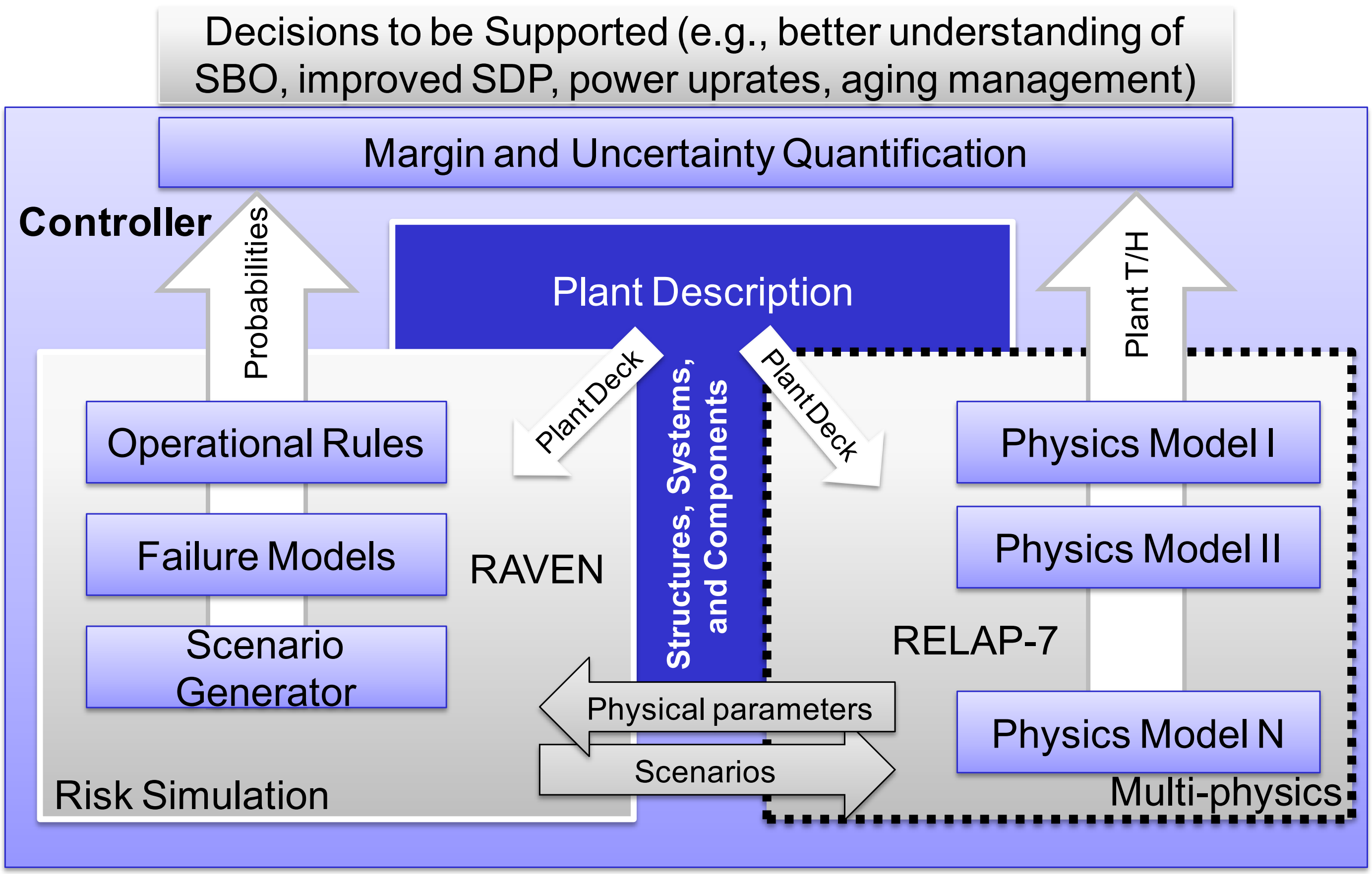
What is RISMC?

- **Loads & capacities are uncertain and can be treated probabilistically**
  - When deterministic margins are evaluated, the analysis is typically very conservative in order to account for uncertainties
- **RISMC uses the probability-margin approach to quantify impacts in order to avoid conservatisms (where possible) and treat uncertainties**



What is RISMC (cont.)?

- **Two types of analysis used in RISMC, probabilistic and mechanistic**
  - In applications, a blended approach is used where both types of analysis are combined to support a particular decision

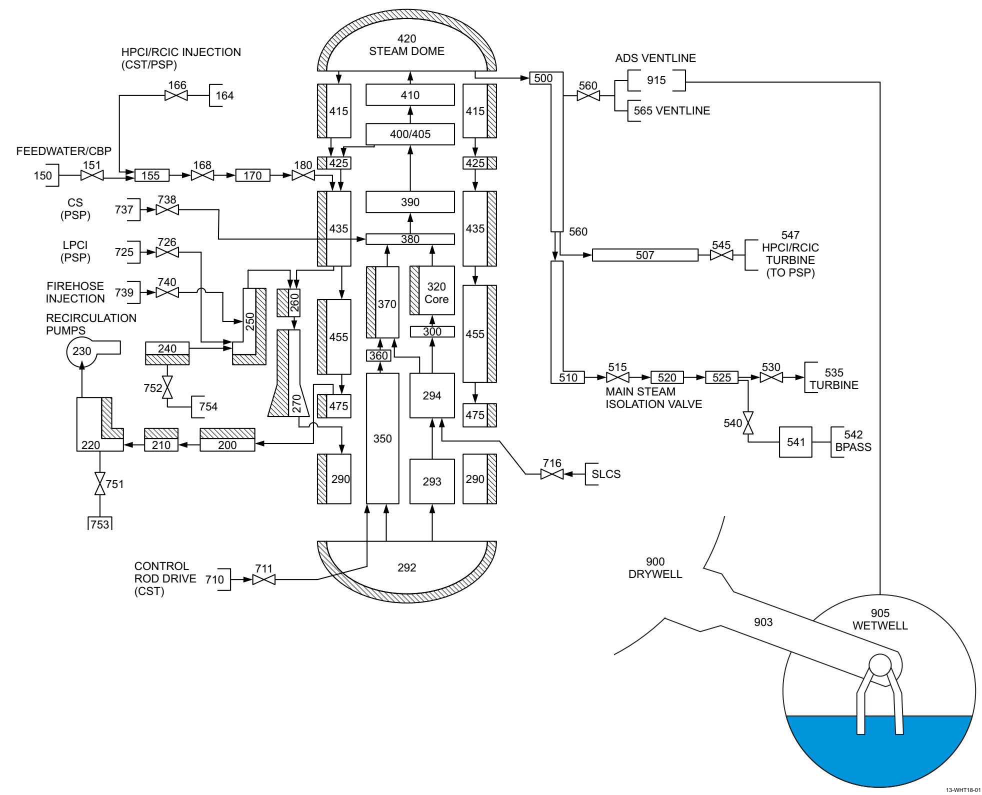


The types of decisions that will be assisted by RISMC

- **Risk-Informed Margin Management will support a variety of safety margin decisions, including recovery of or increasing safety margins…**
  - If core power levels are increased
  - If a different type of fuel or clad is introduced
  - If aging phenomena becomes more active over long periods of plant operation
  - If advanced control systems provide additional or new information during normal and off-normal plant operation
  - If plant modifications are taken to increase resiliency for hazards such as flooding and seismic events
  - If systems, structures, or components are degraded or failed
  - If under accident conditions, supporting severe accident guidelines

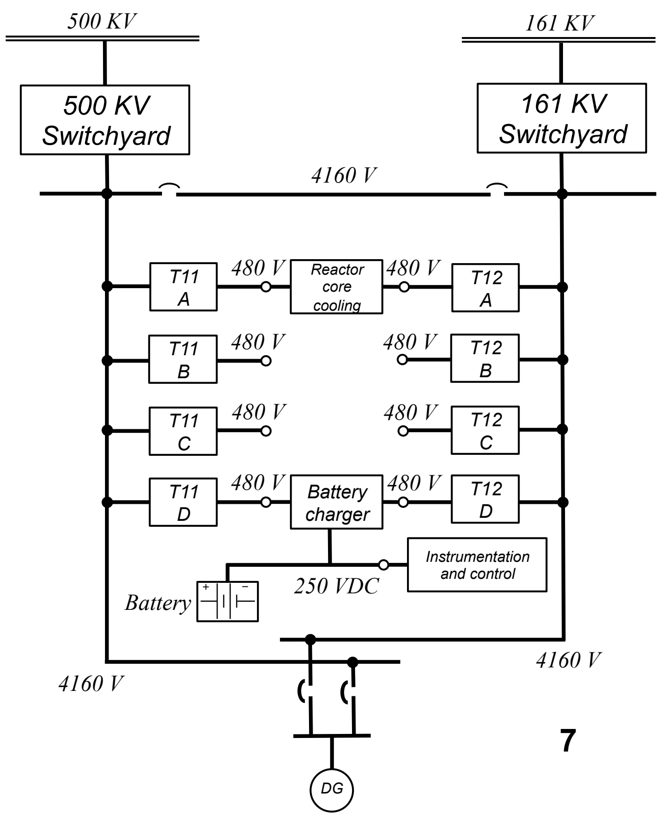
SBO Test Case: Overview

- **Plant considered: BWR with Mark I containment**
- **Test case: Loss of Offsite Power (LOOP) + Loss of Diesel Generators**
- **Objectives:**
  - Evaluate impact of power uprate on LOOP+SBO accident scenario
  - Show capabilities of simulation based PRA through RISMC
  - Compare results with classical PRA tools (SAPHIRE)

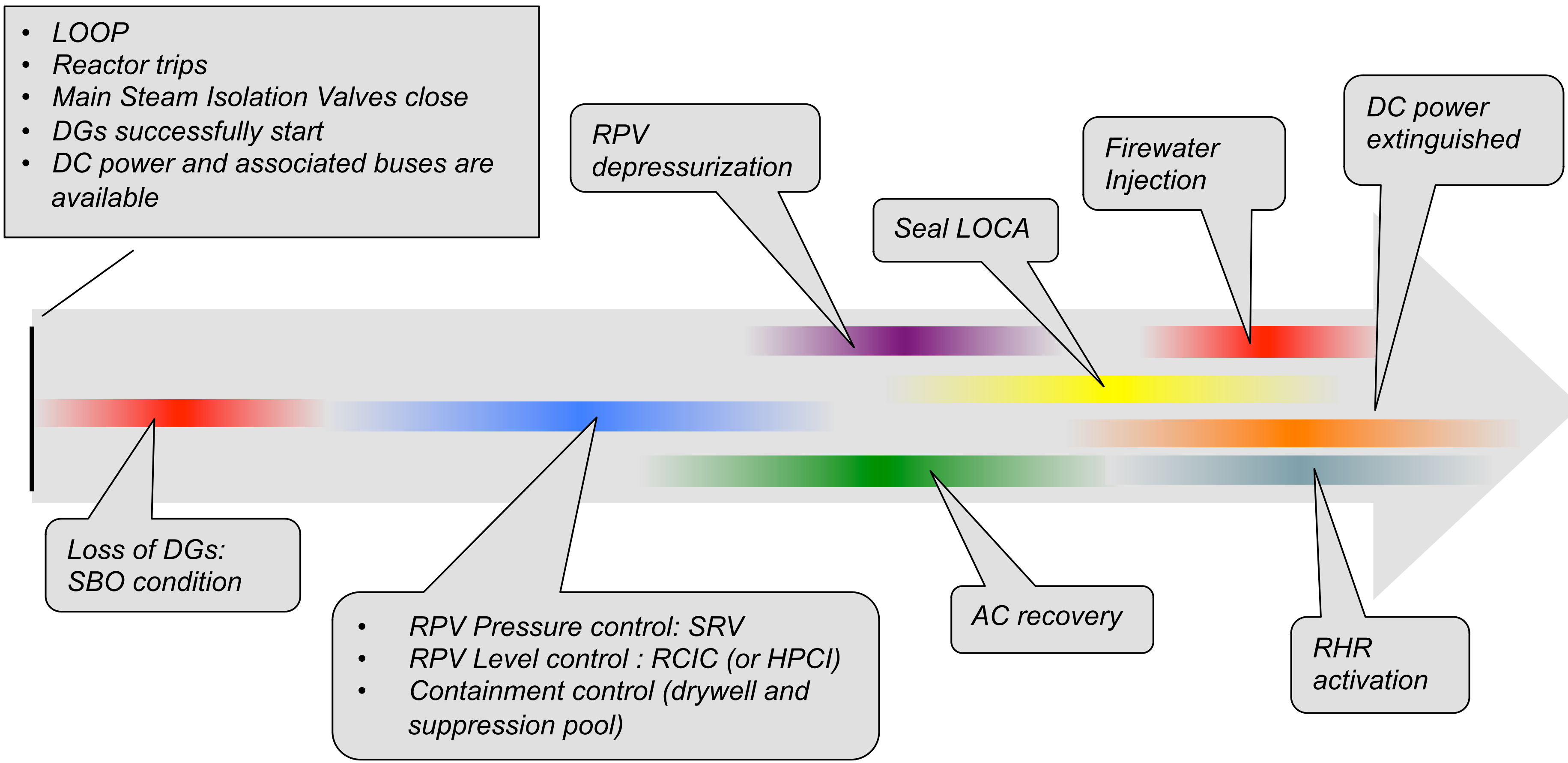


Test Case: Overview

- **Items considered**
  - Reactor Pressure Vessel (RPV) level control:
    - *Reactor Core Isolation Cooling System (RCIC)*
    - *High and Low Pressure Core Injection (HPCI and LPCI)*
  - RPV pressure control:
    - *Safety Relief Valves (SRVs) including ADS*
  - Containment:
    - *Drywell (DW)*
    - *Suppression Pool (SP)*
  - Reactor pump seal
  - Firewater injection system
  - Operators
  - Power Systems
    - *Battery systems (DC systems)*
    - *Normal and emergency AC Power systems:*
      - Power-grid
      - DGs

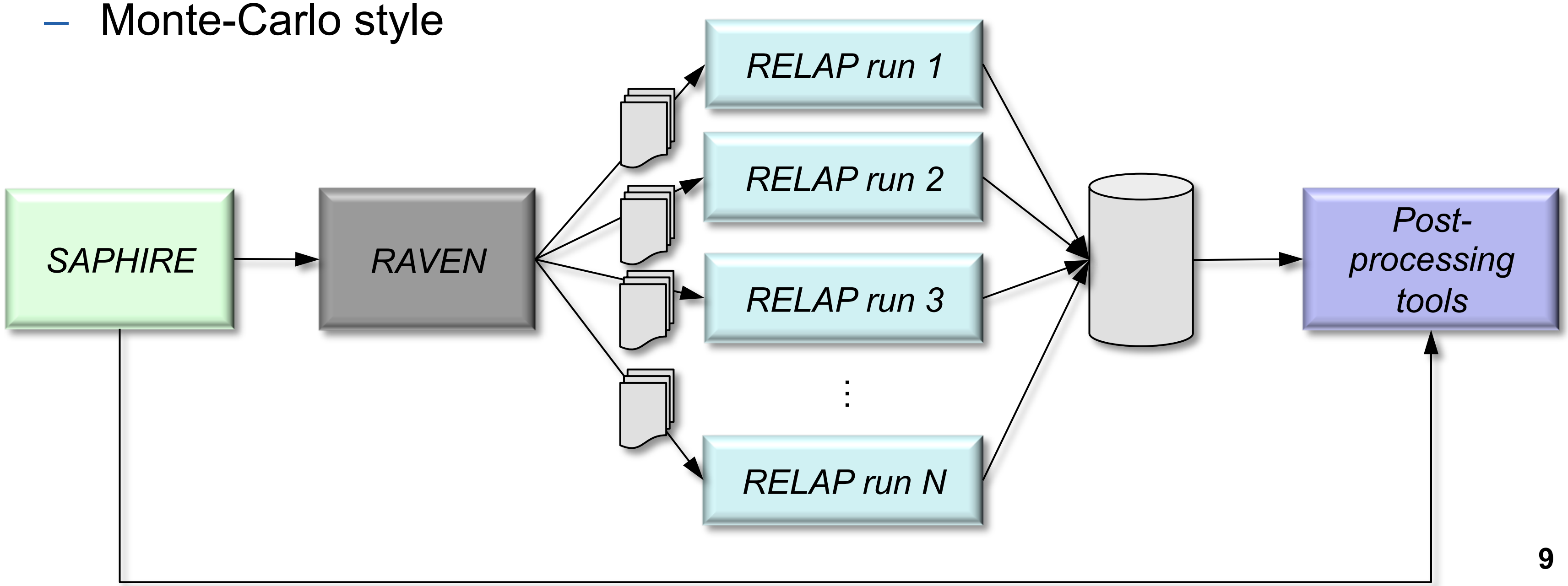


Test Case: Scenario Example



Methodology and Tools

- **Current Tools**
  - SAPHIRE: reliability data
  - RELAP-5, RELAP-7: T/H simulation
  - RAVEN: stochastic analysis
- **Methodology**
  - Series of independent RELAP runs
  - Monte-Carlo style



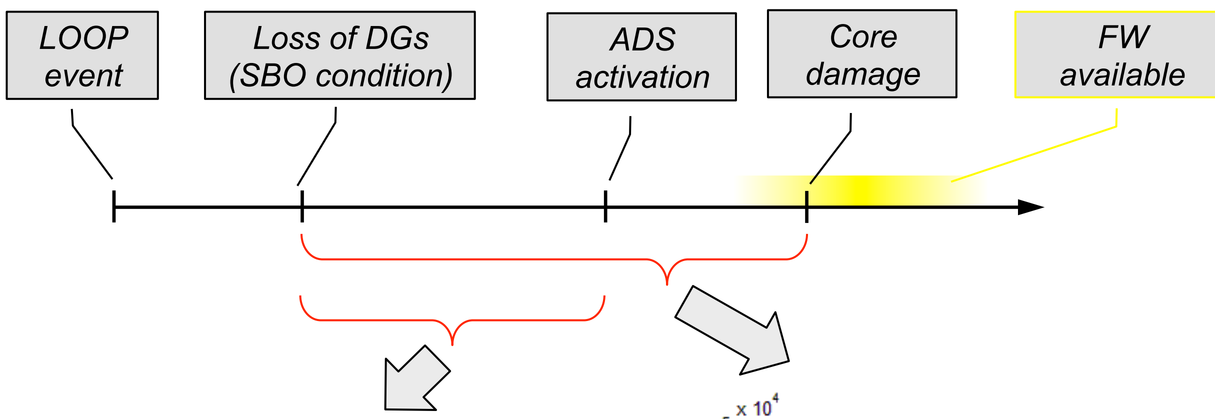
Simulation Info

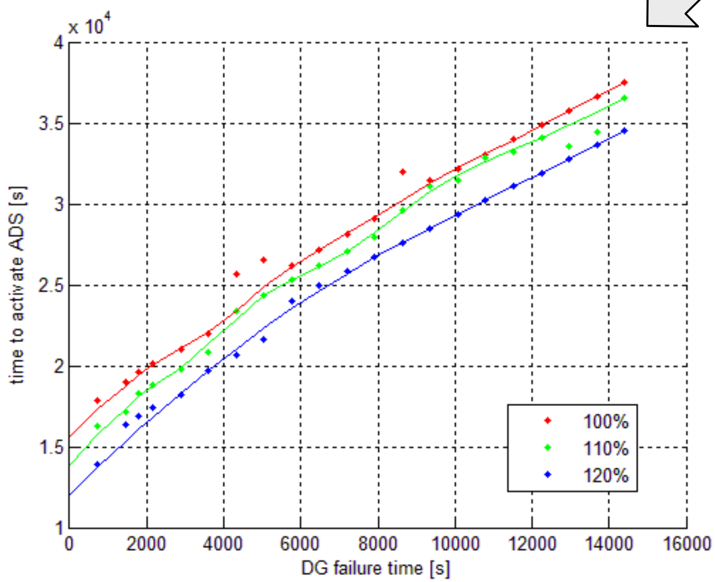
- **Monte-Carlo analysis:**
  - 20,000 LOOP+SBO sequences
- **Stopping conditions:**
  - AC power restored
  - Max clad temperature reached
  - Max containment pressure reached
- **No severe accident analysis considered**
- **Operator actions considered**

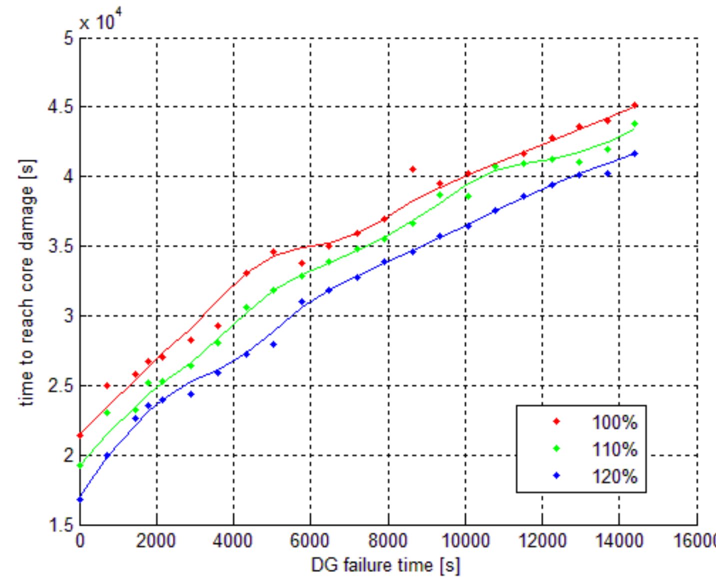
#	Stochastic human interventions
1	Manual ADS activation
2	Firewater injection
3	Extended ECCS operation (battery life)
4	Increase CST capacity
5	Containment (SP) venting

SBO Test Case Results

- **Impact on timing of events**



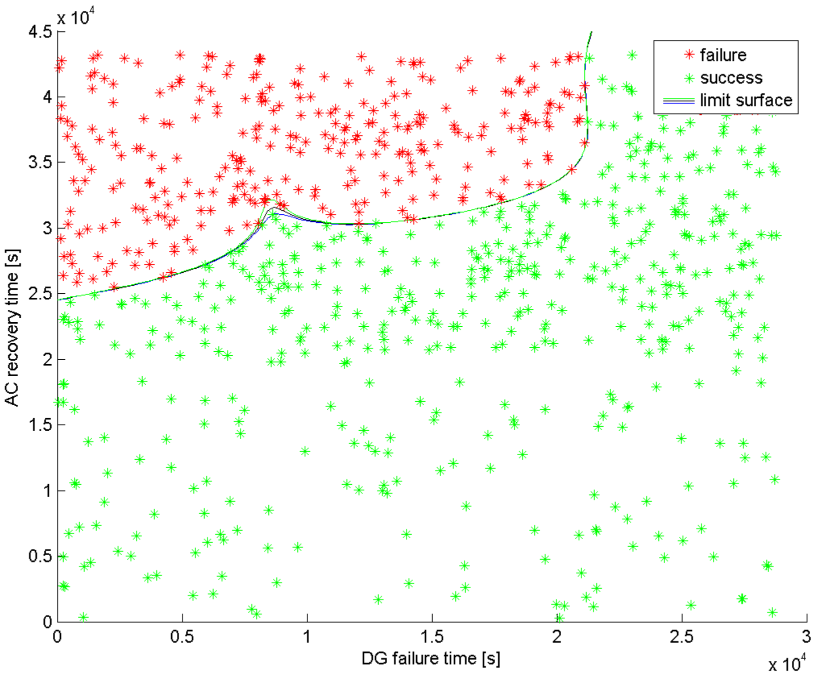




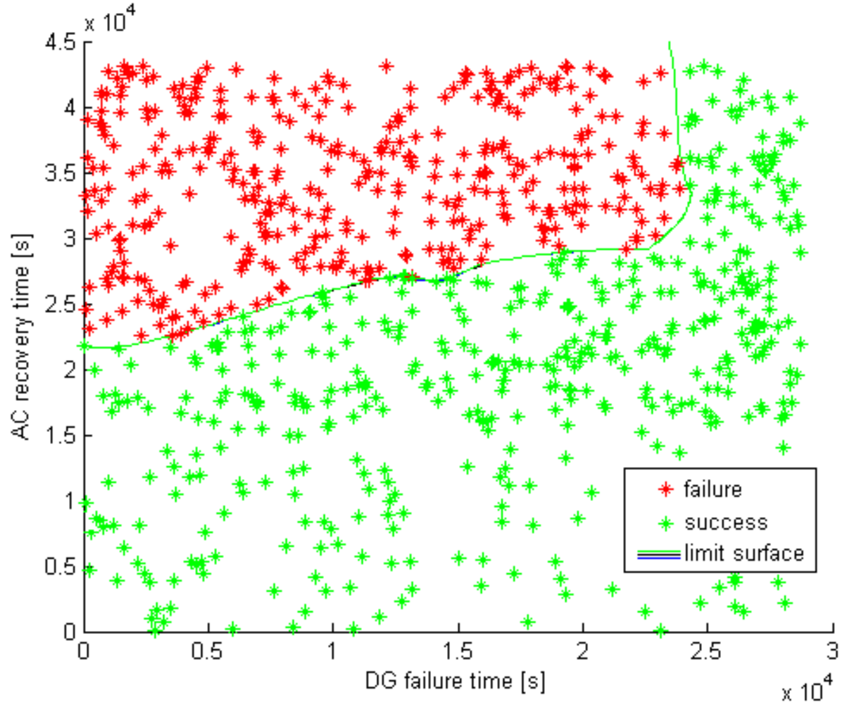
SBO Test Case Results

- **Limit surface: boundaries in the input space between failure and success**
  - DG failure time vs. AC power recovery time

100% power



120% power



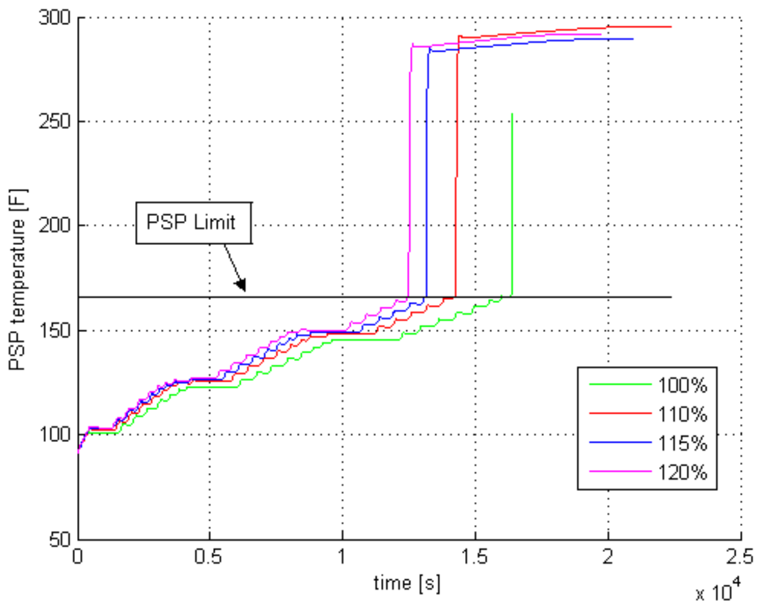
Conclusions

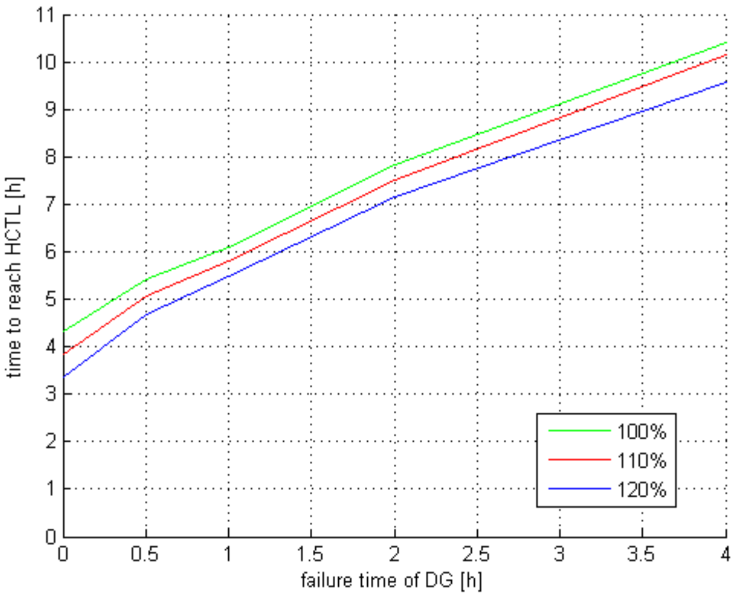
- **RISMC case study aims to risk-inform decision makers about impact of power uprate on system safety**
  - Provides information for Risk Informed Margins Management
- **Analysis is performed using both classical and dynamic PRA methods**
  - Simulation-based tools could be used to validate classical PRA approaches
- **New algorithms have been also developed:**
  - Simulation of systems, components, and operators
  - Limit surface evaluation
  - Data analysis tools

Backup Slides

SBO Test Case Results

- **Impact on timing of events**

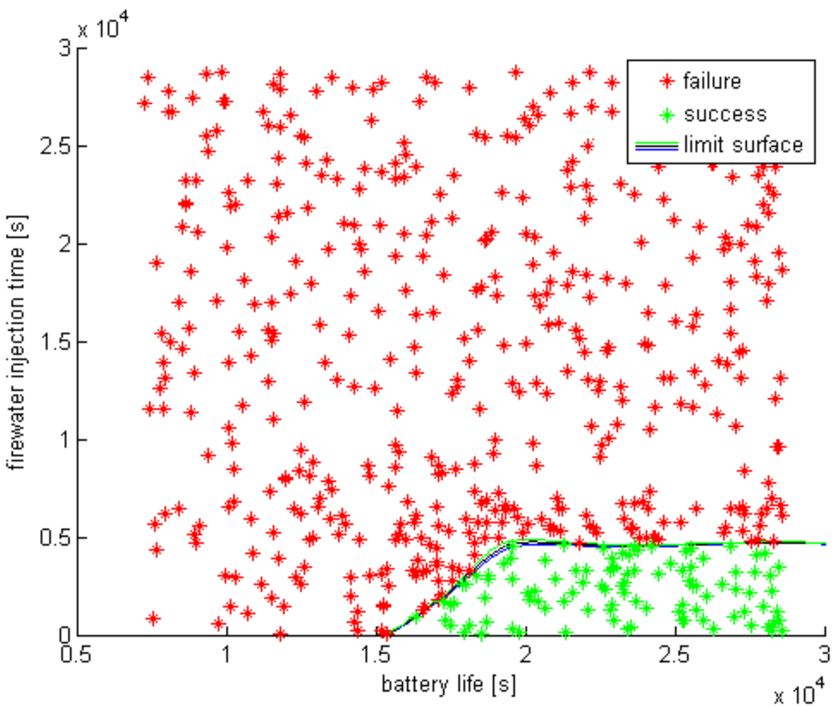




SBO Test Case Results

- **Limit surface: boundaries in the input space between failure and success**
  - Battery life vs. firewater injection time

100% power



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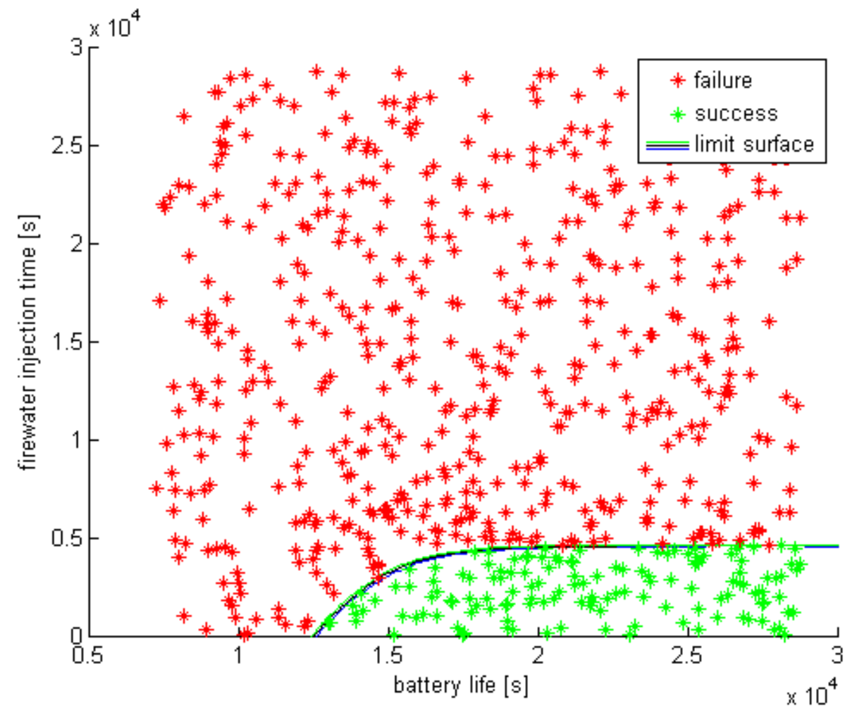
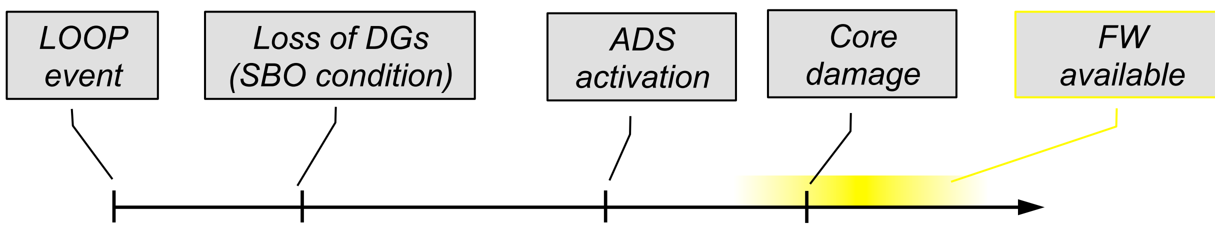
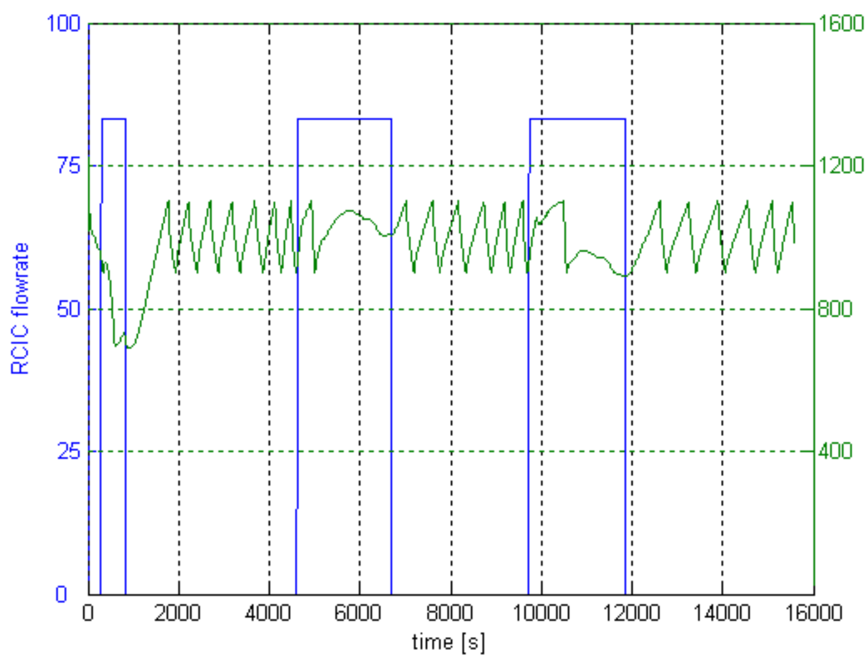
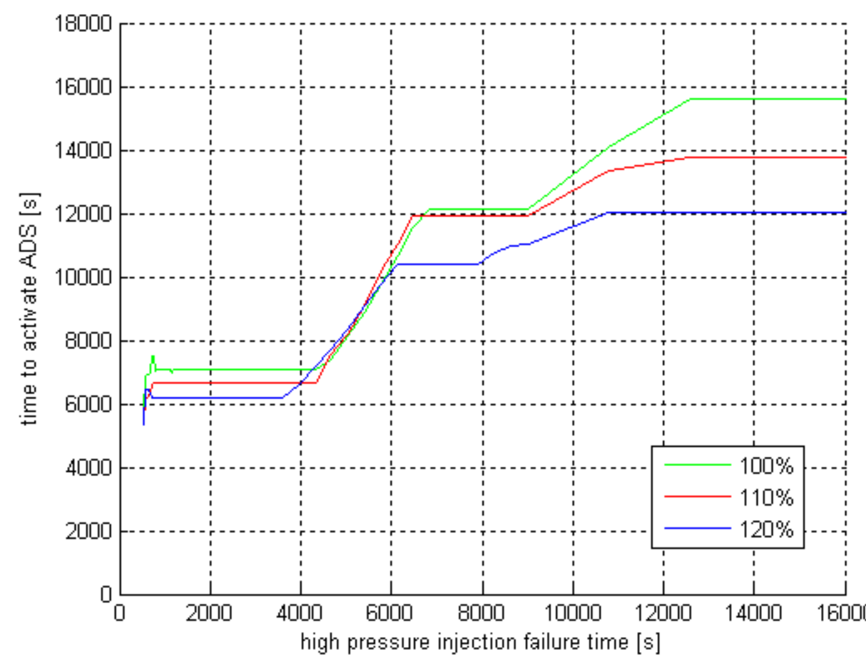


SBO Test Case Results

- Impact of HP injection failure time (both RCIC and HPCI)

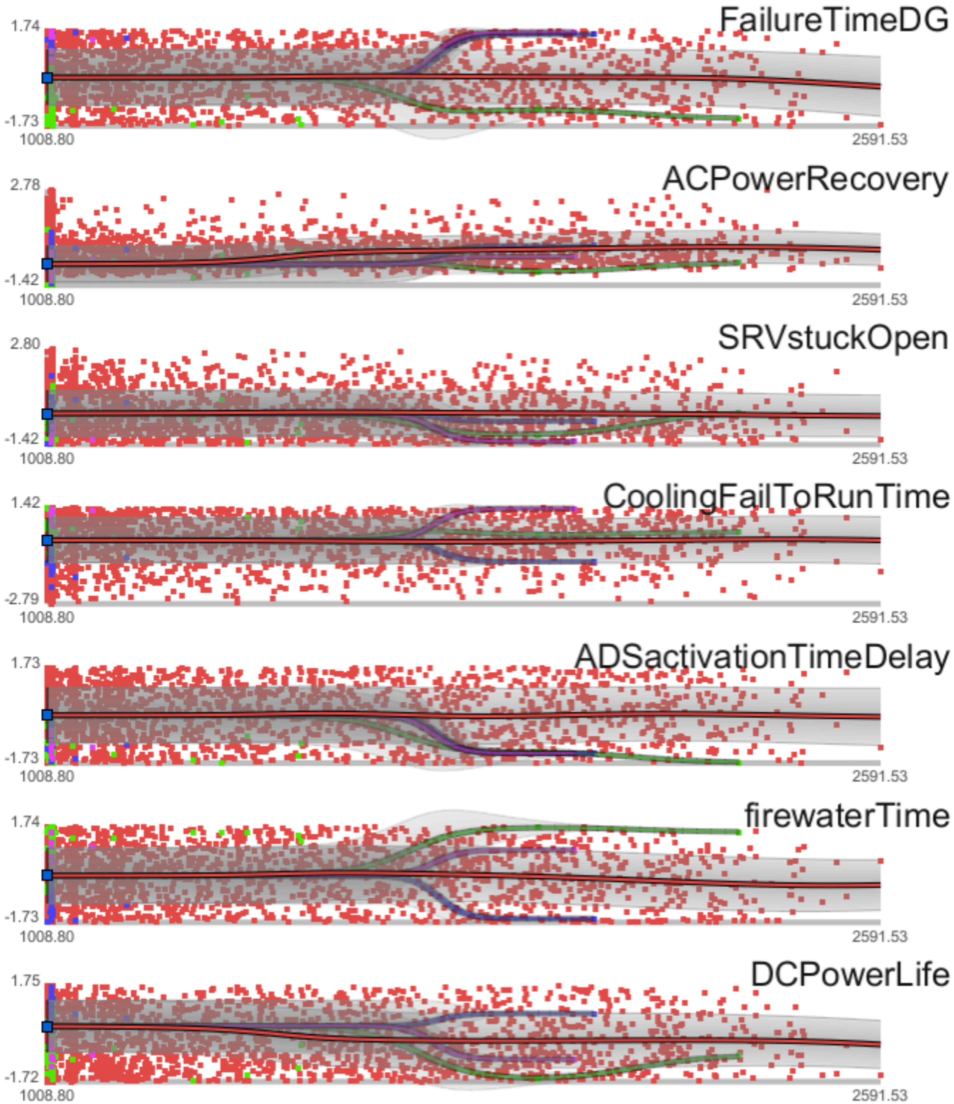






SBO Test Case Results

- **Analysis of the 20K runs**
  - Sensitivity analysis of uncertain parameters on final simulation outcome and margin analysis
  - Metrics:
    - *<u>Max core temperature (success cases)</u>*
    - *Time to reach core damage (fail cases)*



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